UNITED STATES PATENT APPLICATION

FOR

MOLECULAR TRANSFER LITHOGRAPHY

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MOLECULAR TRANSFER LITHOGRAPHY

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5   Research Projects Agency (DARPA). The government has certain rights to this invention.

RELATED INVENTIONS

This application relates to, claims the benefit of the filing date of, and incorporates

by reference the United States provisional patent applications entitled "Micro-Transfer

Lithography", # XX/XXXXXX, filed Feb. 12, 2001, "Production of Integrated Circuit

10   Patterns using Micro-Transfer Lithography", # YY/YYYYYY, filed Mar. 4, 2001, and

"Molecular Transfer Lithography", # ZZ/ZZZZZZ, filed Mar. 16, 2001, which are all

assigned to the assignee of the present invention.

FIELD OF THE INVENTION

This invention relates to a new technique for pattern formation using a

5   photosensitive process, and more particularly describes the application of this technique

to the formation of microscopic patterns for the fabrication of integrated circuits and

other microdevices.

BACKGROUND OF THE INVENTION

10   Many kinds of photosensitive imaging systems have been developed and found

commercial application. The most common is photographic film, manufactured using a

thin emulsion containing silver halide crystals coated onto a plastic or paper support

material. Here, photoexposure creates microscopic changes in the silver halide crystal

structure. These then serve as nucleation points for the transformation of silver halides

15   into metallic silver during subsequent chemical processing, which develops this "latent

image" into an image with far greater contrast and visibility.

Likewise, for integrated device fabrication, photosensitive polymers called

photoresists are in common use. These materials are designed to change molecular

weight with photoexposure, either by photo-induced crosslinking or photoinduced

20   scission. For the processing of integrated devices, a substrate (often a silicon wafer, and

often comprising partially fabricated devices as well) is coated with this polymer, and

photoexposure to define a pattern for processing occurs. The regions of photoexposure

can be defined using lenses and a photomask or reticle, but can also be done by contact

printing with a mask placed directly against the photoresist. The "latent" image after

exposure in this case is the polymer film with a variation in density, or molecular weight.

The polymers of different molecular weight have different solubilities, and so

development occurs when the photoresist is treated with a suitable solvent, and the more

5   soluble material dissolves, leaving the less soluble material behind.

Although many other photosensitive imaging systems have been created, a common

feature of all of them is that they place the photosensitive material on the substrate where

it is ultimately to be exposed, developed and used.

This can lead to problems, especially for integrated circuit manufacturing.

10   Integrated circuits are fabricated layer by layer, with the circuit elements in each layer

defined by a separate lithographic process. After several layers have been manufactured,

the circuit is no longer flat, but can have considerable topography. Although common

photoresist coating techniques, such as spin coating, can work extremely well for flat,

planar surfaces, it can be much more difficult to produce a uniform layer of photoresist

15   on a surface with topography.

There are several reasons that a uniform photoresist layer is desired for lithography.

First, it is commonly known that reflections from the front and rear surface of the

photoresist layer optically interfere, and the overall reflectivity of the film can range from

nearly 0% to almost 90%, depending on the exposure wavelength, coherence, and the

20   layer thickness. Films of different thickness in areas of different topography will have

different reflectivity, which means that different exposure doses are required to achieve

identical results in the different areas. Furthermore, for the formation of microstructures,

the depth of focus is often as small as the typical resist thickness. Focus conditions will therefore be different in areas of different topography.

In addition to this, residues of previous processing steps can contaminate subsequent photolithographic coatings. Chemically amplified resists, for example, are extremely sensitive to amines. A trace amount of amines on the surface can change the lithographic sensitivity by an order of magnitude. Other lithographic applications, such as the formation of amino acid sequences using lithographically defined patterns, may be even more sensitive to this contamination problem.

There have been several innovations to correct this in photolithography. One approach to the problem is to introduce space filling "dummy" features to the design layout, which have no electrical function but serve to make the layer more uniform in profile. This has been used with some success, as described, for example, in "New Data Processing of Dummy Pattern Generation Adaptive for CMP Process" by Shinichi Ueki et al., Proc. SPIE 3748, pp 265-272 (1999). These features are, however, fabricated at the same time as the electrically active features, and must therefore be of the same material as the layer itself (e.g. polysilicon or aluminum). These dummy features are therefore not always electrically inert, but can add unwanted capacitance and inductance to the neighboring circuit.

Other approaches have attempted to increase the depth of focus of the imaging system, using for example interference effects from phase-shifting masks. This has been described in Chapter 5 and the references therein of the book <u>Resolution Enhancement Techniques in Optical Lithography</u>, by Alfred K.K. Wong. This has also proven to be

very useful in some circumstances. However, phase shifting masks are not inexpensive, and their use also introduces other problems in the IC design process.

Recently, there has been a new investigation into the limits of contact printing lithography, adapting techniques for stamping mass manufactured compact audio and video disks for stamping microdevices. Some of these have been described, for example, in "Step and Flash Imprint Lithography: A New Approach to High-Resolution Patterning," by C.G. Willson et al., Proc. SPIE 3676, pp 379-389, (1999) and "Imprint Lithography with 25-Nanometer Resolution" by Stephen Chou et al., Science 272, pp 85-87 (April 1996). These techniques have even been applied to novel curved surfaces in "Patterning curved surfaces: Template generation by ion beam proximity lithography and relief transfer by step and flash imprint lithography," by C.G. Willson et al, in J. Vac. Sci. Technol. B 17(6), pp 2965-2969, (1999).

Although these reflect a great degree of innovation and creativity, all have in common that a master pattern, such as a photomask or an imprint master, is created, and the pattern then directly transferred by some process into the final material

SUMMARY OF THE INVENTION

We propose here an alternative technique, in which the exposure of a photoresist layer is carried out on a separate, planar substrate, and in which this layer of material containing a latent image is then physically transferred to the final substrate for subsequent development and processing. We call this procedure Molecular Transfer Lithography.

The physical transfer of the exposed material is made possible by the suitable choice of a binding layer to the initial substrate, and by the use of an adhesion promotion layer placed between the photosensitive layer containing the latent image and the final substrate.

5   By carrying out coating and photoexposure using planar substrates under optimum imaging conditions, film thickness uniformity can be assured, depth of focus for microstructures is much less of a problem, and the risk of contamination is significantly reduced.

This also enables lithography on otherwise difficult surfaces, such as spheres or

10   cylinders. This is done by initially pattering the photosensitive material on a planar but deformable surface under optimum exposure conditions, and then deforming the substrate (which can, for example, be a bendable plastic) to conform to the curved surface. The material with the pre-exposed latent image would then be directly transferred, without the need to invent techniques for the uniform coating of spheres and cylinders with

15   photosensitive materials.

BRIEF DESCRIPTION OF THE DRAWINGS.

FIGURES 1a-1f show cross section diagrams illustrating the sequence of steps carried out in a typical prior art lithography process.

20   FIGURE 2a shows cross section diagrams of the carrier and substrate according to the present invention, and FIGURES 2b-2c illustrate the sequence of steps for photoexposure of the carrier according to the process of the current invention.

FIGURES 3a-3d show cross section diagrams illustrating the transfer of a latent image from carrier to substrate and the subsequent development of the latent according to the process of the current invention.

FIGURE 4a illustrates the steps taken in an initial reduction to practice; FIGURE 4b shows cross section diagrams of the carrier and substrate as prepared in the initial reduction to practice, and FIGURE 4c illustrates the transfer step in the initial embodiment.

FIGURE 5 presents a micrograph of the mask used in the first reduction to practice.

FIGURES 6a –6b present measurement results that confirm the film has been transferred.

FIGURE 7 presents a micrograph of a transferred structure after development.

FIGURES 8a – 8b illustrate a second reduction to practice for the invention.

FIGURES 9a-9c illustrate details a third reduction to practice for the invention.

FIGURES 10a – 10c illustrate details of a fourth reduction to practice for the invention.

Note: All drawings in cross section are for illustration purposes only. The dimensions of the layers in these illustrations are not shown to scale, nor should any conclusion about the desired relative thickness of the layers be drawn from these illustrations.

DETAILED DESCRIPTION OF THE INVENTION

As indicated above, this invention is a new approach to the formation and subsequent development of latent images. Although the concept of forming a latent image is known in the art, and the processes for development here are not new, latent images are typically formed on the surfaces or substrates where they are to be developed. This is illustrated in FIGURE 1. As FIGURE 1 also shows, certain problems with uniformity of film thickness and substrate topography can have consequences for the final image as well, either from interference effects or from depth of focus problems.

FIGURE 1a shows a cross section of a substrate 100 with topography features 110, which has been processed with a layer 120 to be patterned using lithography. The next step is to apply a photosensitive material, typically a photoresist polymer to form a coating 130 of photoresist. This material is not always perfectly conformal, as illustrated in FIGURE 1b.

FIGURE 1c shows exposure of the photosensitive material using selective exposure to photons or charged particles. Images are formed of several features on a photomask (not shown) by focussing the image on the surface of the layer 120 without topography. For this illustration, the images are of identical dimensions. Exposure of these identical features is shown schematically as identical beams 150 with a waist at the point of smallest focus. The exposure is typically for a set duration of time, with a certain exposure fluence to deliver a specified dose of photons or charged particles to the photosensitive material.

FIGURE 1d shows the photoresist layer structure after photoexposure. For purposes of illustration, we have drawn the situation where exposure has induced crosslinking,

forming a less soluble region in the photoresist polymer. These crosslinked regions 160

occur wherever a suitable dose from exposure beams 150 has occurred.

FIGURE 1e shows the photoresist after being developed by a suitable solvent. The

more soluble photoresist dissolves, leaving behind only isolated resist structures 170 and

5   172 corresponding to the crosslinked portions of the polymer 160. Note that, where

exposure was out of focus, as is the case for the resist feature 172 on top of the

topography 110, the feature is considerable wider than the other resist features 170.

FIGURE 1f shows the final result after the pattern is transferred to the layer 120 to

be patterned. For this illustration, we use the example of etching the layer 120. Where

10   resist features 170 and 172 are present, the layer 120 is not etched, and only small

features 180 and 182 remain. Note that the feature on top of the topography 182

corresponding to the larger resist feature 172 is considerably wider than the other features

180.

The lithography problems illustrated here, of nominally identical features forming

15   non-identical images, and many variations will be known to those skilled in the art of

lithography, and need not be illustrated in further detail here.

In Molecular Transfer Lithography, the process of exposure and processing are

separated, and carried out as two distinct sets of processing steps. These are shown in

FIGURE 2 and FIGURE 3.

20   In FIGURE 2a, we show in cross section, as we did in FIGURE 1, the substrate 200

with topography 210 and a layer 220 of material to be patterned. In this illustration, this

also has an additional coating 225 of an adhesion promotion material. However, as also

shown in FIGURE 2a, a new, planar substrate 201 is prepared. We have called this new

substrate a "Carrier" substrate. This substrate 201 can be of any size, but is typically of

the same general dimensions as the device to be manufactured. It can be made from any

material suitable to the final task of molecular transfer. For general applications, quartz

substrates of high quality and good surface figure are easily obtained, while certain

5   plastic substrates might also be used for situations requiring deformation prior to

adhesion. Other possible carrier materials are silicon wafers, gallium arsenide wafers,

various glasses, and various polymeric materials.

The carrier 201 is coated with several uniform layers: a removal layer 215, a

photosensitive coating 230, and an adhesion layer 235. These facilitate respectively

10   removal from the carrier, photosensitivity and the formation of a latent image, and

adhesion to the structures on the final substrate 200. The most important property of the

layers is that the transfer removal layer 215 (which may be a distinct material or an

interface) can be selectively disassociated from coating 230 containing the latent image

and that the photosensitive coating 230 remains photosensitive when placed in contact

15   with the other layers. This disassociation may occur either inherently, or with subsequent

chemical modification, such as dissolution through the introduction of a solvent.

It is advantageous where the adhesion and removal layers are processed to achieve

the desired effect of selective adhesion and removal. For example, the removal layer 215

may begin as a tightly bonded material connecting the photosensitive material 230 to the

20   carrier 201. However, after contact with the substrate 200, a second processing step, such

as the introduction of a solvent, can cause the disassociation of the photosensitive

material from the carrier 201 through breakdown of the removal layer 215.

The removal layer 215 can comprise nothing, if the surface energy of the resist with the carrier is low enough, or be a layer of a low energy material such as teflon, or a dissolvable material, such as another photoresist or any other dissolvable polymer material. The removal layer 215 may also comprise a material that can change phase, for

5 example from a solid to a liquid, by processing such as thermal effects or absorption of directed radiation. For example, such materials may be waxes or metals, respectively. These materials may be deposited on the carrier surface using standard spin-coating or sputtering techniques. In addition, the removal layer 215 may be the same as the photosensitive coating itself 230 where the transfer occurs by delamination of the

10 photosensitive coating.

The photosensitive coating 230 can be selected from a variety of photosensitive materials, such as commercial polymers that undergo chemical or physical changes when exposed to radiant energy. These are often called photoresists. Both negative and positive photoresists can be used, depending on the specific application.

15 The adhesion layer 235 must have a higher surface energy when placed in contact with the materials on the substrate 200 , so common surface preparations such as hexamethyldisilazane (HMDS) can be used.Curable polymers, such as epoxies or other photoresists, can also be used. If this layer is applied prior to photoexposure, the optical properties of the material must also be considered, since UV absorption by the adhesion

20 layer 235 could affect the exposure dose used. Alternatively, the adhesive layer 235, which can be as simple as a single monolayer of HMDS, may be applied after the exposure step, and UV absorption is less important.

It should be noted that this adhesion layer 235 may comprise nothing, if the relative

adhesion properties of the layer 225 and 215 applied onto the substrate and carrier have

suitable adhesion properties. It will also be understood by those skilled in the art that the

adhesion layer 235 on the carrier and adhesion layer 245 on the substrate must have

5   suitable adhesion properties to each other to promote the eventual adhesion of the

photosensitive layer 230 to the substrate after latent image formation. This may also

include subsequent processing steps to improve adhesion after the initial contact is made.

Such processing steps include thermal processing where the diffusion of the material

interfaces can occur to improve bonding, or to facilitate a chemical reaction, such as

10   cross-linking.

To create the lithographic pattern, the carrier 201 with photosensitive coating 230 is

exposed to a suitable pattern of radiation 250. This is illustrated in FIGURE 2b. Any one

of a variety of commonly practiced lithographic techniques can be used. Exposure can be

accomplished by contact lithography with a mask and flood UV exposure. It can also be

15   carried out using standard imaging techniques in a standard stepper or scanner,

commonly used for IC microfabrication, as long as the stage has an adapter to properly

hold and align the coated carrier. Direct write techniques, such as E-beam lithography or

other directed energy exposure techniques, can also be used to expose the photosensitive

layer 230. Many other exposure techniques will be known to those skilled in the art.

20   After exposure has occurred, a latent image exists within the photosensitive

material. This is illustrated in FIGURE 2c. This latent image comprises regions which

have been altered by exposure, along with regions which have remained unexposed and

unaltered For the purposes of illustration, FIGURE 2c shows the exposed regions 260 formed by crosslinking to be less soluble after exposure to the radiation beams 250.

FIGURE 3 illustrates the transfer and processing steps of Molecular Transfer Lithography. Here, the carrier 201 with the latent image containing the crosslinked regions 260 is aligned with the substrate 200 using an alignment system 290. The alignment system in FIGURE 2c is simple, and those skilled in the art will know many variations of highly precise alignment techniques that can be applied to this situation. The two objects, once aligned, are then brought into physical contact or at least very close physical proximity.

If the carrier adhesion layer 235 and substrate adhesion layer 225 have a suitably larger surface energy relative to the removal layer 215, the layer 230 containing the exposed regions 260 will detach from the carrier 201 and adhere to the substrate 200. This is illustrated in FIGURE 3b. The carrier 201, now with no coating, is then removed, leaving the photoresist layer 230 with exposed regions 260 on the substrate 200.

Additional processing steps, along or in combination, can also be used at this point to enhance the transfer of the exposed layer from the carrier to the substrate. Heat can be applied to the pair, to change the relative adhesion properties, or to increase the number of binding or interacting molecules across the interface. Pressure can also be applied. A special gas can be directed to surround the materials, again to affect the relative adhesion properties. Exposure to UV light or other directed energy beams can also be applied at this point, to cause selective photochemistry in some or all of the layers (such as curing an epoxy, for example). The substrate 200 or carrier 201 can also be configured to allow the insertion of a suitable solvent for at least one of the layers, to selectively dissolve a

layer binding the latent image to the carrier and therefore promote adhesion to the substrate. In addition, the cohesiveness of the materials may be designed such that removal of the carrier from the film structure may be accomplished by separation (or tearing) of the removal layer. Many other transfer promoting or transfer inhibiting

5   techniques will be known by those skilled in the art.

After transfer has successfully occurred, development of the transferred photoresist layer 230 and subsequent processing of the substrate would proceed as in a regular photolithographic process, as shown in FIGURE 3c, creating photoresist regions 270 which correspond to the exposed regions260.

10   FIGURE 3d shows the final patterning of layer 220, in which resist regions 270 form barriers to an etching process, leaving patterned regions 280 that are the same size regardless of the underlying topography. both with and without topography 210

Although originally conceived as a technique for the fabrication of integrated circuits, there are many other applications where this patterning technique can be utilized,

15   for example in the area of organonucleotide sequencing.

Currently, bio-chips containing many variations of organonucleotide sequences are fabricated using sequences of lithography steps. Each patterning step allows the additional attachment of one nucleotide to the sequence. Large sequences in a variety of combinations are built up using masks with complicated array patterns, repeating the

20   steps of exposure, development, nucleotide attachment, resist removal, etc. until the entire array of desired sequences has been produced.

This is very time consuming and tedious. Furthermore, the processing steps, using

sequences of masks that must be used in the correct lithographic order, make queueing

for exposure tool time a problem for practical production.

This problem is relieved if pre-exposed carriers containing latent images of the

5   masks have been fabricated in advance. Then, to create the appropriate step of the

nucleutide sequence, the carrier is simply brought into proximity with the substrate, and

the latent image transferred to the substrate. No delay for coating is required, and more

importantly, there is no delay for expensive exposure tool time.

Similar queueing advantages may in fact be found in any fabrication technique

10   based on the invention disclosed here, whether they be for bio-chips, integrated circuits,

photonic devices, micro-electromechanical systems (MEMS), or other microdevices, as

long as a pre-stocked inventory of stable pre-exposed latent images can be effectively

stored without aging or contamination problems.

15   <u>DESCRIPTION OF VARIOUS REDUCTIONS TO PRACTICE</u>

To demonstrate Molecular Transfer Lithography, the following experimental

processes were carried out. These are also illustrated in FIGURES 4 through 10.

For the first reduction to practice, illustrated in figure 4, the carrier substrate 201

was a quartz substrate 0.5 mm thick and 25 mm by 25 mm in area. This was coated with

20   Shipley 310i negative photoresist 230 using spin coating at 4000 rpm. Because this

material had a suitable surface energy, no additional removal layer 215 was required.

The reductions to practice used a conventional contact or proximity lithography

system to generate the latent image. However, those skilled in the art will recognize that

many lithographic techniques, including projection lithography systems using reduction lenses, can also be used to implement this invention.

The photoresist was exposed using contact lithography with a mask and flood exposure from a 1 kW Hg(Xe) Arc lamp. An image of the mask structures taken from an optical microscope at 20X magnification is shown in FIGURE 5. The arc lamp was filtered, so only UV light with wavelengths of 220 – 250 nm exposed the photoresist. The exposure time was 1 second using an Oriel lamp, Model number 66921 which utilizes a UV grade fused silica F/1 condenser. The substrate 200 for this demonstration was a silicon wafer, coated with the adhesion layer. For this example, the adhesive layer 225 was a monomolecular HMDS layer, placed on the surface by standard vapor priming techniques This typically produces a monolayer of the HMDS on the surface.

After photoexposure, the carrier with the latent image in photoresist was placed in physical contact with the silicon wafer with HMDS. After being placed in contact, the carrier/substrate combination was heated to 120°C for 90 seconds on a bake plate 400 within an enclosed chamber 420, as shown in FIGURE 4c. The carrier was then cleaved from the surface by applying lateral force to the carrier, leaving the entire photoexposed film attached to the silicon wafer. Those skilled in the art will recognize that other more delacate removal methods may also be applied to separate the carrier from the substrate, and that less force is required if suitable adhesion properties are chosen.

In FIGURE 6, we depict the measurement of the thin imaged layer of photoresist taken by a spectrometer before and after the transfer. The absence of fringes after transfer indicates the film is no longer present on the carrier.

In FIGURE 7, we show an image of the developed photoresist on the substtrate, taken using an optical microscope with a 50X magnification lens.

For the second reduction to practice, as illustrated in FIGURE 8, a quartz plate and a silicon wafer were again used as the carrier 201 and substrate 200, respectively. After the silicon had been primed with HMDS, however, an additional layer of Shipley 310i photoresist 835 was coated onto the substrate at 4000 rpm using standard spin-coating procedures. The thickness of the photoresist film at this spin-speed is roughly 550 nm. The quartz carrier was exposed using the same conditions as those mentioned in the first reduction to practice. The carrier containing the latent image within its own layer of Shipley 310i photoresist was then brought into contact with the substrate coated with HMDS and Shipley 310i. The combined carrier and substrate were then heated to 110C using an enclosed chamber. The quartz carrier was then removed from the wafer. With this method, the transfer occurred within the exposed Shipley 310i, as film remained on the substrate after removal; however the imaged material also was observed on the carrier. This observation indicates a lateral separation within the exposed material , causing it to split. This results in a portion on the wafer and a portion on the quartz carrier itself. The advantage of this method is improved wetting at the substrate and carrier interface, as well as smaller disassociation force required. This method may also be useful for top surface imaging strategies, such as silylation based techniques, of transferring images.

For a third reduction to practice, as illustrated in FIGURE 9, a quartz plate with a layer of Shipley 310i was again used as the carrier 201 and photosensitive layer 230 the latent image formed by exposure for 1.0 seconds using the Oriel exposure system

previously described. A silicon wafer primed with HMDS was used as the substrate 200. After the silicon had been primed with HMDS, however, an additional layer 935 of Shipley UVN2 photoresist 530 nm thick was added to the substrate by standard spin coating techniques. The quartz carrier containing the latent image within Shipley 310i

5   was then brought into contact with the UVN2 coated substrate. The two adhered structures were then exposed to UV light 950 at wavelengths from 220nm to 250nm for 2 seconds as illustrated in FIGURE 9c. The exposure was performed through the back of the quartz carrier 201. The structures were then heated to 110C on a conventional hotplate. This results in cross-linking of the material with diffusion across the interface

10   of the imaged material and the UVN2 photoresist on the substrate. After heating the carrier was removed by applying a lateral force to induce a disassociation within the latent image film.

For the fourth reduction to practice, illustrated in FIGURE 10, a modified quartz carrier 1001 containing capillary channels 1010 was used as the carrier. This carrier was

15   first coated with an adhesion layer 215 made up of Shipley 3612, a positive photoresist, using spin coating at 4000 rpm to produce a film thickness of 1.7 microns. This was then and was then uniformly exposed to UV radiation at wavelengths from 220-250 nm for 10 seconds. This degraded the photosensitivity of the photoresist and reduced the molecular weight. The quartz carrier with 3612 resist was then baked at 120C for 4 minutes. A

20   photosensitive layer 230 of Shipley 310i was then spin coated at 4000 rpm onto the hardened exposed 3612 photoresist. The photosensitive 310i layer was then imaged using a contact lithography procedure, as described above. This carrier was then brought into contact with the silicon substrate. As in the third reduction to practice, above, the

surface of the silicon substrate was primed with HMDS and a coated with layer of UVN2 as in the manner previously described. The carrier and the silicon were then heated to 120C for 60 seconds.

Disassociation of the carrier from the silicon was achieved by adding a small

5   quantity (two drops) of Shipley LDD26 to a 750 micron capillary channel 1010 within the carrier. To maintain planarity in the region of lithographic interest, the holes in the carrier should be placed to the sides of the carrier, away from the region where transfer will occur. The developer flowed into the hole and within the region between the carrier glass and silicon substrate by capillary action. The previously exposed Shipley 3612

10   photoresist was then dissolved away. The advantage of this chemical approach is that small disassociation forces are needed to pull the carrier away from the substrate, and the approach is robust with respect to variations in the surface energy of the quartz carrier.

Other methods of achieving this process include first coating the carrier with a standard "top-coat material" such as JSR NFC620 which is typically used as a top anti-

15   reflective coating. Next, the photoresist layer is coated onto the carrier. The top-coat materials are typically water soluble, do not mix with the photoresist, and are transparent. All of these are desirable properties. After the photoresist is imaged and contacted to the surface of the substrate, water may be added to the structure. Because the photoresist is insoluble in water, only the top-coating layer is weakened. This aids in lowering the

20   forces needed to remove the carrier from the latent image, and thus disturbing the latent image.

While specific materials, coatings, carriers, substrates, and process steps have been set forth to describe and exemplify this invention and its preferred embodiment, such

descriptions are not intended to be limiting. Modifications and changes may be apparent to those skilled in the art, and it is intended that this invention be limited only by the scope of the appended claims.